POWER QUALITY ESTIMATION AND CLASSIFICATION USING WAVELETS

Bachelor of Technology in Electrical Engineering

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Under supervision of

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POWER QUALITY ESTIMATION AND CLASSIFICATION USING WAVELETS

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

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CERTIFICATE

This is to certify that the Thesis report entitled “**POWER QUALITY DETECTION AND CLASSIFICATION USING WAVELETS**”, submitted to the National Institute of Technology, Rourkela by **Mr. Deepak Ku.Ekka** , Roll No: 110EE0194 for the award of Bachelor of Technology in Electrical Engineering is a bona- fide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements. The draft report which is based on candidate’s own work has not been submitted elsewhere for a degree/diploma. In my opinion, the draft report is of standard required for the award of a Bachelor of Technology in Electrical Engineering.

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DEFINATIONS OF DIFFERENT POWER QUALITY DISTURBANCES

As defined by the **IEEE** the various disturbed signals are:

SAG: It may be defined as the sudden drop of the voltage magnitude from its nominal value typically lasting from a cycle to a second or so, or tens of milliseconds to hundreds of milliseconds.

SWELL: sudden rise of voltage magnitude from its nominal value typically lasting from a cycle to a second or so, or tens of milliseconds to hundreds of milliseconds.

INTERRUPTION: sudden drop of the voltage magnitude from its nominal value to negligible or very less magnitude. It can be momentary, temporary or long term.

SURGE: Sudden rise of voltage magnitude for a very short period.

HARMONICS: It is the sinusoidal component of a periodic wave or quantity having a frequency that is integer multiple of fundamental frequency.

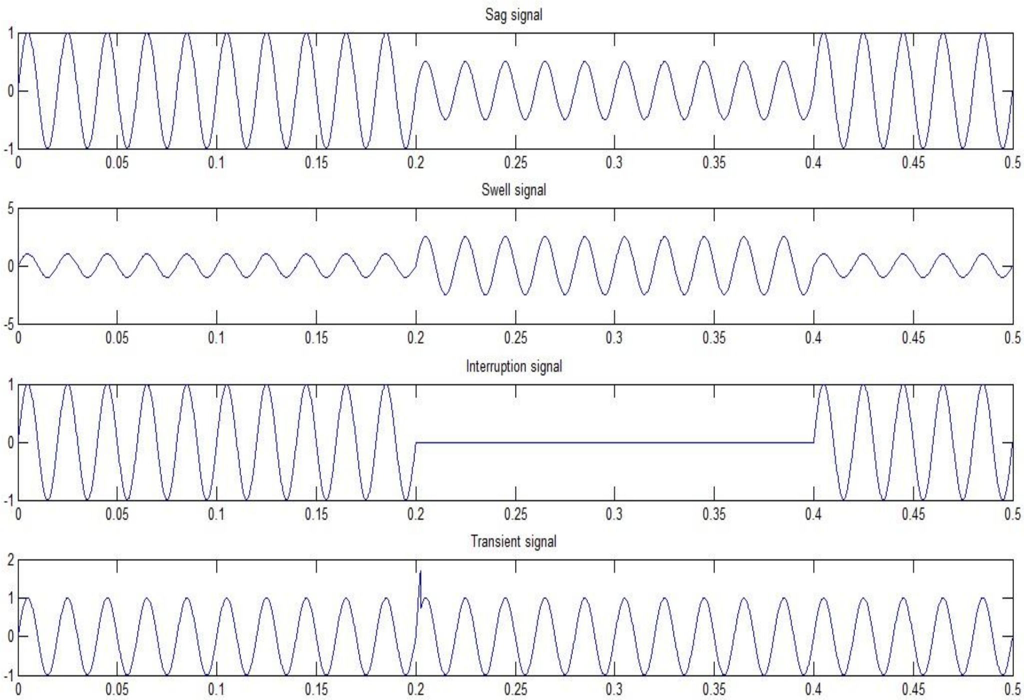

Figure.1 different power quality events

TABLE.1FOR PQ FOR SHORT DURATION INTERVALS

Categories	Duration	Voltage magnitude
1. Sag		
1.1 instantaneous	0.5-30 cycle	0.1-0.9 pu
1.2momentary	30 cycle - 3 sec	0.1-0.9 pu
1.3 temporary	3 sec. – 1min	0.1-0.9 pu
2. Swell		
2.1 instantaneous	0.5-30 cycle	1.1 -1.8 pu
2.2momentary	30 cycle - 3 sec	1.1 -1.4 pu
2.3 temporary	3 sec. – 1min	1.1 -1.2 pu
3.Interruption		
3.1momentary	0.5-30 cycle	< 0.1 pu
3.2 temporary	3 sec. – 1min.	< 0.1 pu

TABLE OF PQ FOR LONG DURATION INTERVAL

Categories	Duration	Voltage magnitude
1.Long Durationvariation		
1.1 Interruption	>1 min.	0.0 pu
1.2Under-voltage	>1 min.	0.8-0.9 pu
1.3 Over-voltage	>1 min.	1.1-1.2 pu
2.Transient		
2.1 Impulsive(millisecond)	>1m sec	0-4 pu
2.2Oscillatory	0.3-50 m sec.	

ABSTRACT

Due to increase in the number of electric and electronic equipment along with the fast controlling power electronic devices, which has affected the main power quality events(PQ).These are namely short-circuits , notching, voltage sag and swell, harmonics and transient due to load switching. Whenever these disturbances occur, these last for few cycles and simple observation of waveforms in the bus-bar will not help to recognise the problem in there and henceforth will not be able to identify and sort out the problem. If such events occur for few more cycles/minute it may result to overvoltage and under-voltage, or long time power interruption or any other problem.

Hence, an approach is developed for the detection and location of time and finally classifies the different power quality events including both the transients and steady state signals. By using one of the signal processing we can decompose namely wavelet decomposition by using "**DISCRETE WAVELET TRANSFORM** (DWT)".In a sampling frequency, we can samples those signals and any change on the smoothness is detected at finer resolution levels of decomposition. By the decomposition process we get the power coefficients or wavelet packets which are necessary performance indices of the signal. We are in generally using the

a) THD (Total Harmonic Distortion) and

b) Energy of the signal to classify them in the PQ event analysis.

The main purpose of the paper also focuses on using the MATLAB WAVELET TOOL GUIDE, for the study of De-noising and other purpose.

Also we have to understand the mathematical tools used in the discrete wavelet transform (DWT) starting from the decomposition algorithm to the de-noising as well as thresh-holding of the PQ signals which are necessary in monitoring the classification scheme.

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LIST OF ABBREVIATIONS

PQ –POWER QUALITY

DWT-DISCRETE WAVELET TRANSFORM

FT-FOURIER TRANSFORM

STFT-SHORT TIME FOURIER TRANSFORM

FFT-FAST FOURIER TRANSFORM

THD-TOTAL HARMONIC DISTORTION

SNR-SIGNAL TO NOISE RATION

MSE-MEAN SQUARE ERROR

Chapter I INTRODUCTION

As discussed earlier that now-a-days due to power electronic equipments and its increasing use in the industry, the power quality (PQ) getdetoriated. Most of the equipments are sensitive to thevariations in power quality. Some of the problems associated with the poor quality are malfunctioning, short lifetime, power interruption, over voltages and under voltages. Therefore it has become a dire need to monitor and detect the disturbances as well classify them in an intelligent manner. Comparing with the other signal processing processes like Fourier Transform (FT), Short time Fourier Transform (STFT) and Fast Fourier Transform, which makes an analysis just in spectral analysis ad is applied to steady state conditions not in the transients as well as at high frequency.The Discrete Wavelet Transform (|DWT) on the other handis preferred for its window for sampling in the time frequency variations results better in time frequency response.

1.1 MAIN OBJECTIVE OF THE PROJECT :

The main purpose of the project is to develop a signal processing method i.e. Discrete wavelet transform (DWT).It should be able to detect the different power quality events and finally classifying these signals using a classifier based on the feature extraction of the PQ signal.

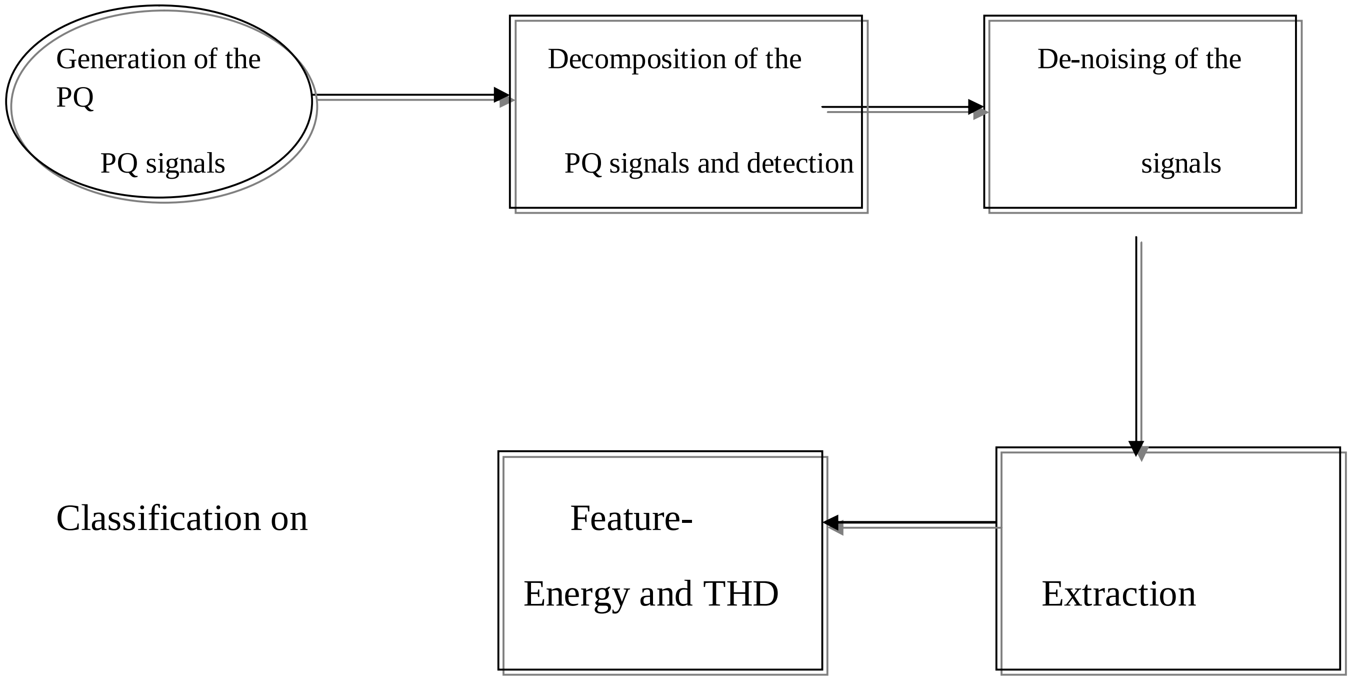

Figure 2.Block diagram for the general process

1.2 BASIC LAYOUT OF THE PROJECT

As shown in the figure.2 the various processes which we are required to carry out the wavelet analysis of the PQ signals which are basically as follows:

1. To generate the power quality signals along with disturbances.
2. To undergo wavelet decomposition as well as reconstruction.
3. To de-noise the PQ signals with noise.
4. Feature extraction of performance index using the coefficients of the wavelets.
5. Finally classifying them based on the basis of THD and Energy of the signal.

CHAPTER I focuses on the need of PQ detection and monitoring scheme for the classification purpose. It also compares the DWT procedures with other signal processing methods.

CHAPTER II focuses on explaining the DWT signal processing methodology. It starts with the definitions and the methods which are required to extract the necessary coefficients namely **approximate** and **detail** coefficients. It also tries to recognise the signals in different frequencies of sampling. Also the problem associated with noise in case of detection is discussed.

CHAPTER III focuses on the de-noising of the signal parameters along with the performance indices like Signal-to-Noise Ratio (SNR) and Mean Square Error (MSE).

CHAPTER IV focuses on the performance indices of the signals. By obtaining the coefficients in wavelet decomposition procedure, we can obtain the THD and Energy of the different PQ signal, which are having different sets of values.

CHAPTER V focuses on classifying them within the threshold limit and by certain parameters. Finally a flow diagram to classify the power signals is made.

Chapter II Application of DWT

2.1 DISCRETE WAVELET TRANSFORM

DWT is a strong mathematical and analytical computing method in signal processing which carries out the transformation of the PQ events. In other words, DWT develops a windowed frame of certain samples taken in the value which can be modulated by signal cutting problem. The only idea of the scheme is to looking different resolutions and time-frequency domain for both steady-state and transients unlike the Fourier Transform (FT). In this paper, we are going to generate different PQ signals and decomposing them in different levels by the DWT and the change in the smoothness of the signal is detected at different resolutions. I t is quite evident that PQ disturbances has the unique deviation from the pure sinusoidal waveform and thus reliable to classify them based on energy concept.

The basic step in the signal processing of the DWT involves two stages which are as follows:

1. Determining the wavelet coefficients
2. Reconstruction of the signal by these coefficients

In brief, the first stage includes determining the wavelet coefficients $h_d(n)$ and$g_d(n)$. These coefficients transform them from the time domain to wavelet domain. After the completion of the first stage, these coefficients are approximated and detailed version of the pure signal. The transformation formula is as shown below:

$$\boldsymbol{cA_1 = \sum_k f(n).\, h_d\,(-k + 2n)} \text{..........................} \textbf{(2.1)}$$

$$\boldsymbol{cD_1 = \sum_k f(n).\, g_d\,(-k + 2n)} \text{..........................} \textbf{(2.2)}$$

Now this process is repeated to obtain the level 2 decomposition and hence all the coefficients on wavelet domain are found out from the time domain by the reconstruction procedure.

FIGURE 3.DECOMPOSITION ALGORITHM

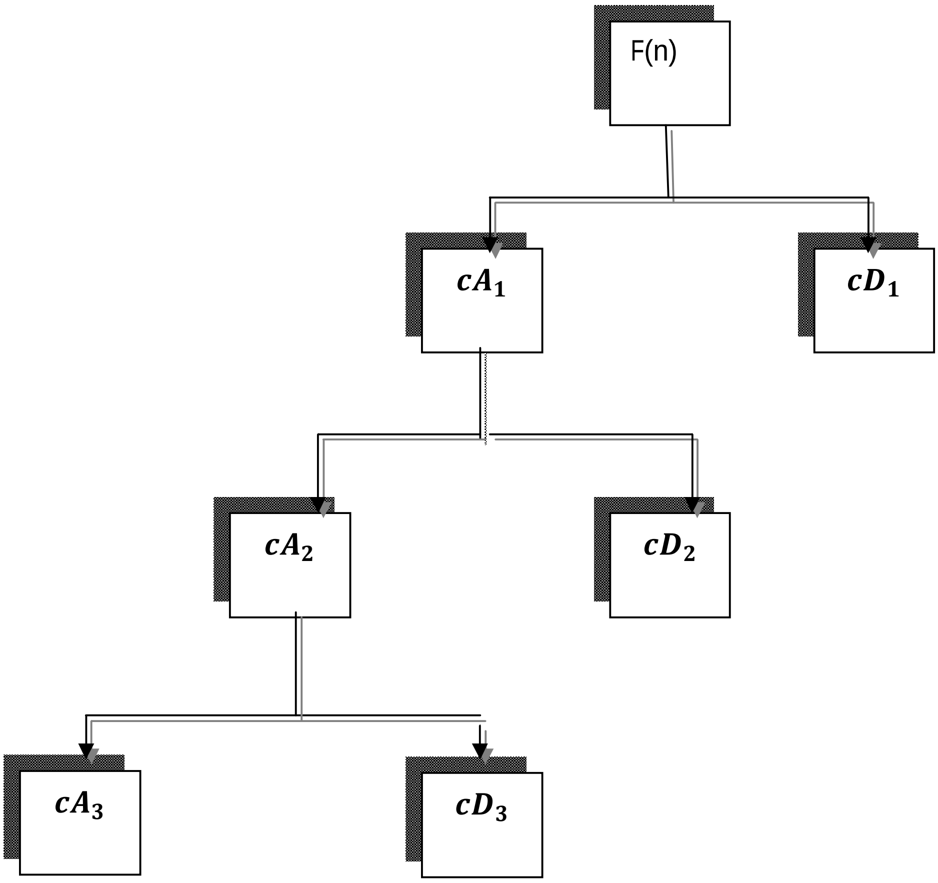

FIGURE 3 BASIC DECOMPOSITION ALGORITHMS

The wavelet transform of the signal is given by

$$\boldsymbol{WT(a,b) = \int_{-\infty}^{\infty} f(t) * a, b(t)dt} \text{..............................}\mathbf{(2.3)}$$

Where $WT(a,b) is the wavelet transform$ of the signal $f(t)$ and

$a, b(t) = \frac{(t-b)}{a\sqrt{a}}$is scaled and shifted from the mother wavelet(t). The parameter 'a' is the scale and time domain property is 'b'.$\frac{1}{\sqrt{a}}$is the normalization value of a,b(t). Here band pass filter is assumed as it has both high pass and low pass characteristics. The low pass filter approximates the signal wheras the high pass filter provides the detail lost in the approximation

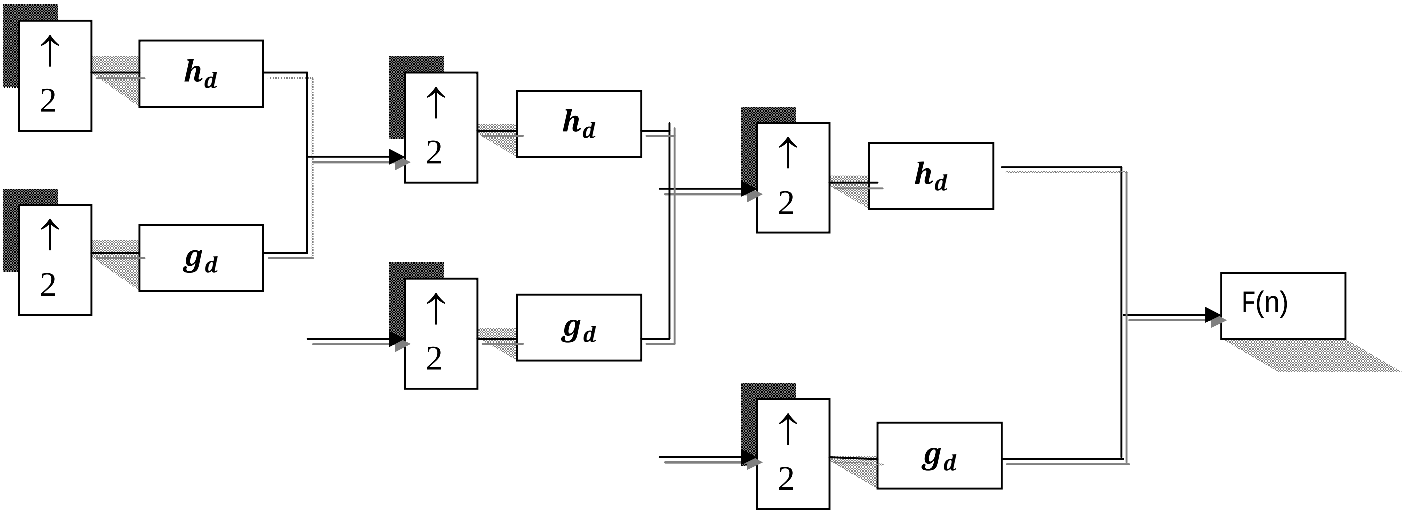

FIGURE 4.RECONSTRUCTION ALGORITHM

Here in the block diagram for the reconstruction algorithmh_d reprsents the low pass filter and g_d repersents the high pass filter which approximates and details during reconstruction algorithm.

Choice of Mother Wavelets

The choice of filter coefficients is very necessary as if not chosen correctly there will be detection problem. As we know there are two types of disturbances: slow transients and fast transients. The waveforms in the fast transients have rapid changes and sharp edges where Daub4 and Daub6 gives better results then the other coefficients due to less time and compactness. In general, Daub8 and Daub10 coefficients are use in slow changes and transients.

2.2 GENERATION OF THE PQ DISTUBANCES

TABLE 2 GENERATION OF DIFFERENT PQ SIGNALS

TYPE OF PQ DISTURBANCES	MODEL EQUATION	VARIATION
Voltage sag	v=(1-A*(u(t-t1)-u(t-t2))).*sin(2*pi*50*t);	A=(0.1-0.9) and t1-t2=(0.2-0.4 seconds)
Voltage swell	v=(1+A*(u(t-t1)-u(t-t2))).*sin(2*pi*50*t);	A=(0.1-0.9) and t1-t2=(0.2-0.4 seconds)
Voltage interruption	v=(1-(u(t)-u(t-t1)+u(t-0.4))).*sin(2*pi*50*t);	A=0 and t1-t2=(0.2-0.4 seconds)
Voltage transient	v=(1+A*(u(t-t1)-u(t-t2))).*sin(2*pi*50*t);	A=2-3 and t1-t2=(0.21-0.22 seconds)
Voltage Sag with third Harmonics	v=(1-A*(u(t-t1)-u(t-t2))).*(sin(2*pi*50*t)+(0.333*(sin(2*pi*50*3*t))));	A=(0.1-0.9) and t1-t2=(0.2-0.4 seconds)
Voltage Swell with third harmonic	v=(1+A*(u(t-t1)-u(t-t2))).*(sin(2*pi*50*t)+(0.333*(sin(2*pi*50*3*t))));	A=(0.1-0.9) and t1-t2=(0.2-0.4 seconds)

The various types of PQ events were generated using MATLAB code using the above equations namely, voltage sag, voltage swell, transients and interruption with harmonic contents.

SPECIFICATION OF THE SIGNALS

Frequency of the signal = 50 Hz

Frequency of sampling = 102.4 kHz

No. of samples = 2048 no. of samples.

Total time of signal = 0.5 seconds.

The interval of disturbances = 0.2-0.4 seconds

2.3 DETECTION USING DWT

From MATLAB codes we have generated the different power quality signal disturbances at the frequency of 50 Hz with a sampling rate of 102.4kHz with 2048 number of samples along with the impact of the disturbances is0.2 seconds to 0.4 seconds. As we know that for more number of decomposition levels we have to decompose with higher sampling frequencies. The accuracy of the detection is dependent on the level of decomposition. So, we have to also compare those signals with two different sampling frequencies namely 102.4 and12.8 kHz.

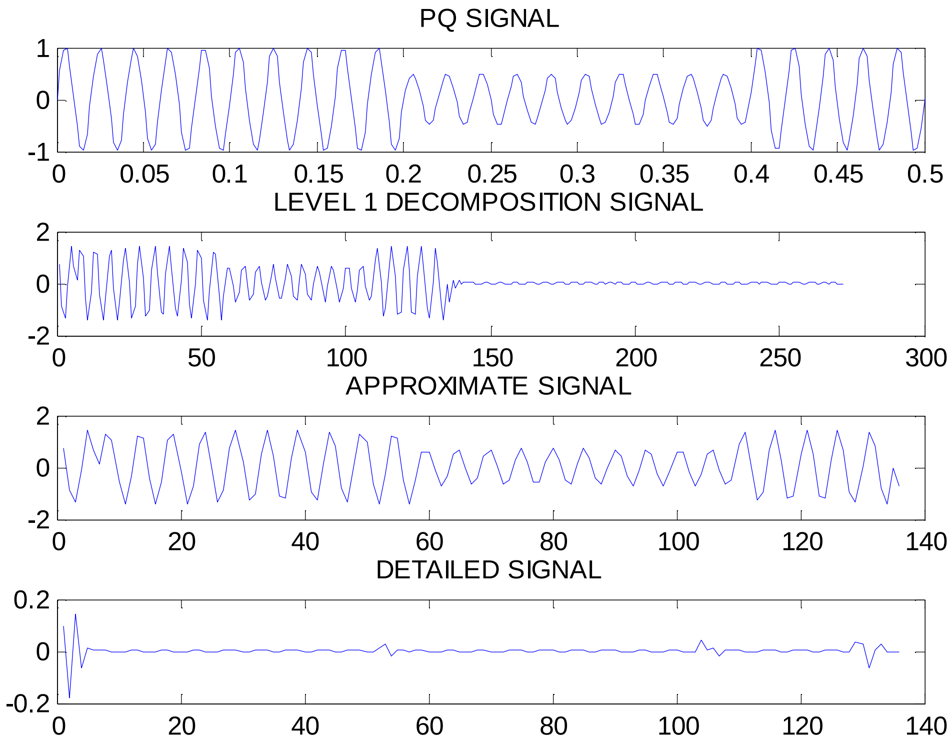

FIGURE5. VOLTAGE SAG WITH 1ST LEVEL OF DECOMPOSITION WITH 256 SAMPLES (12.8kHz)

The voltage signal is generated and by Daub 8, the slow changing power quality events have been decomposed in level 1decomposition of wavelet transform. The approximate and detail coefficients are also obtained only in case of transients the Daub 4 is used. But for further level of decomposition we have to sample those at higher frequency levels namely at 102.4 kHz with 2048 no of samples.

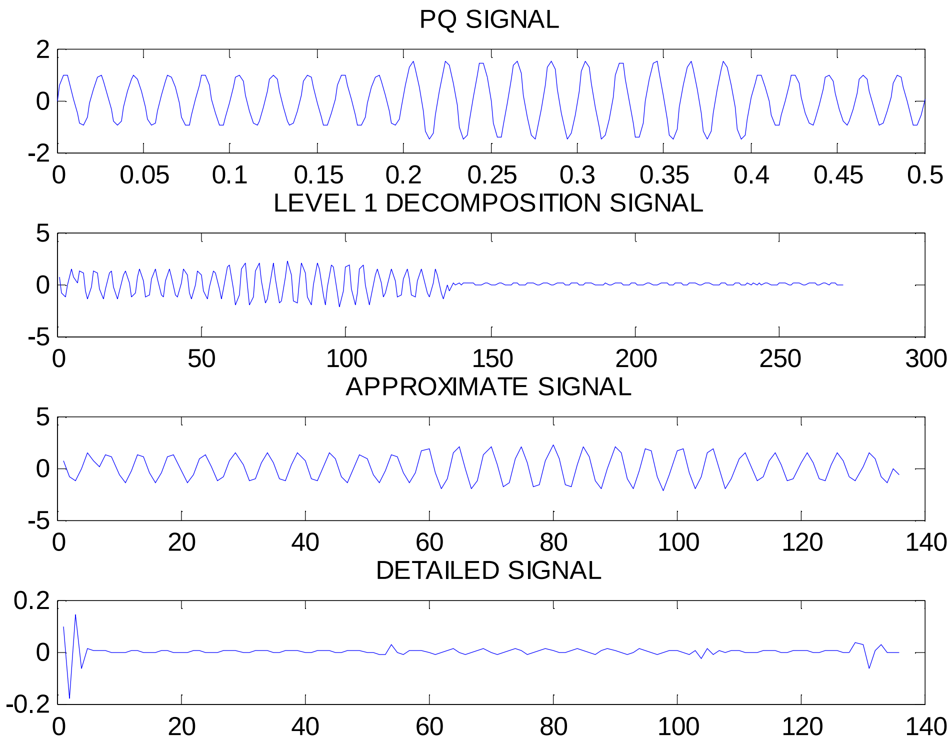

FIGURE6. VOLTAGE SWELL WITH 1ST LEVEL OF DECOMPOSITION WITH 256 SAMPLES(12.8kHz)

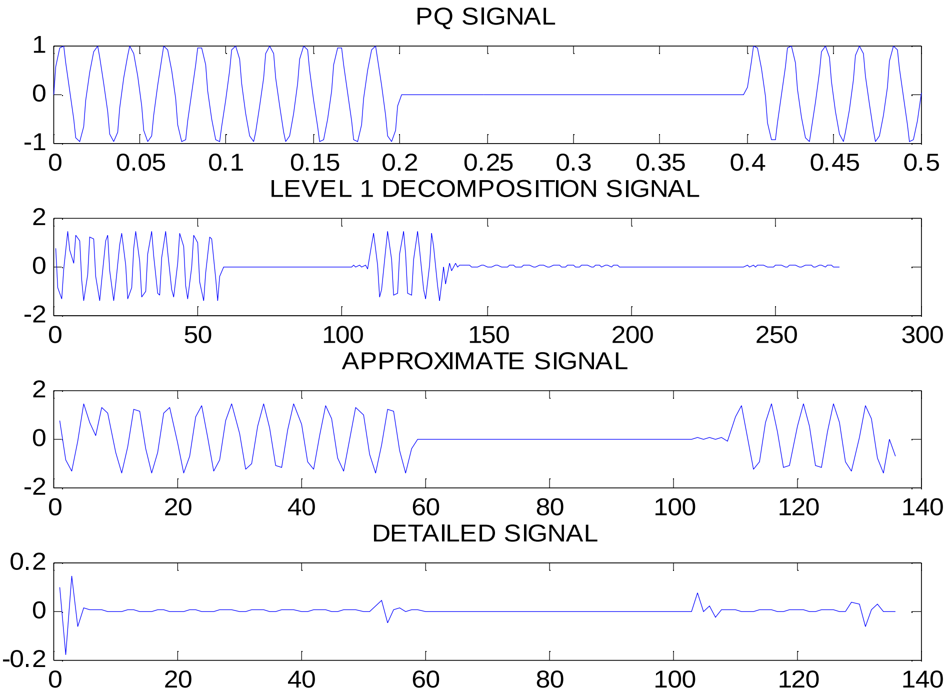

FIGURE7. VOLTAGE INTERRUPTION WITH 1ST LEVEL OF DECOMPOSITION WITH 256 SAMPLES (12.8kHz)

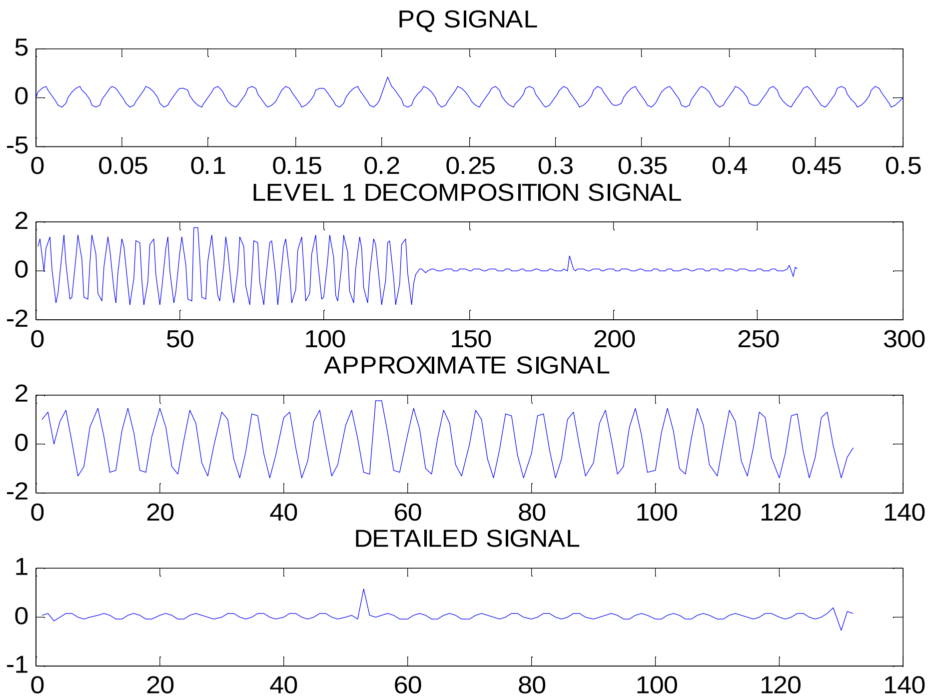

FIGURE8. VOLTAGE TRANSIENT WITH 1ST LEVEL OF DECOMPOSITION

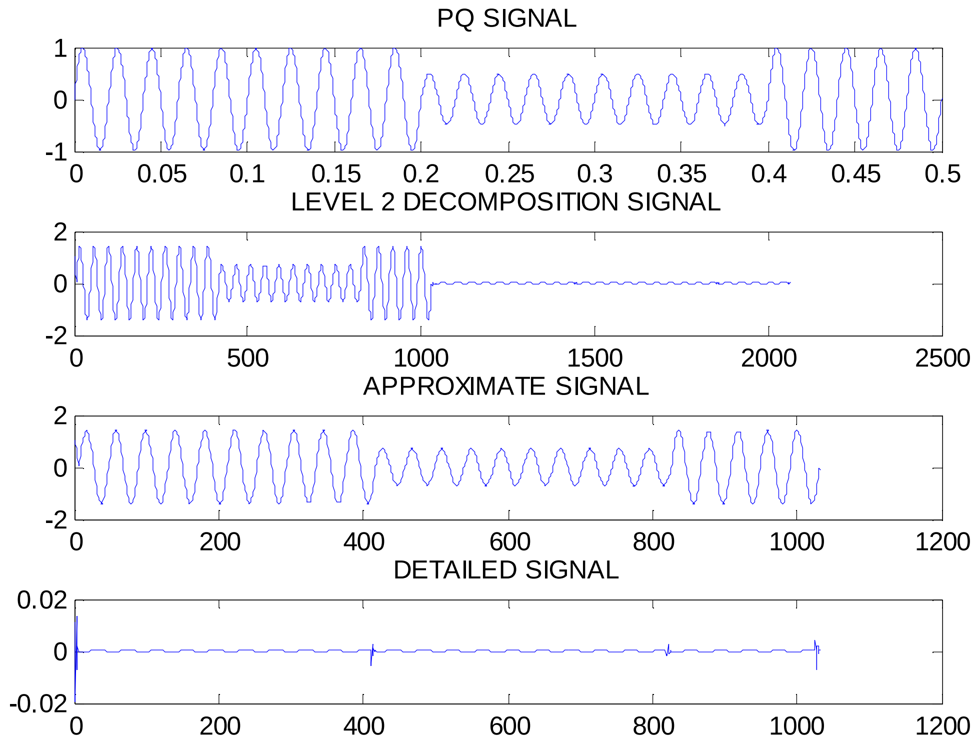

FIGURE9. VOLTAGE SAG WITH 2ND LEVEL OF DECOMPOSITION

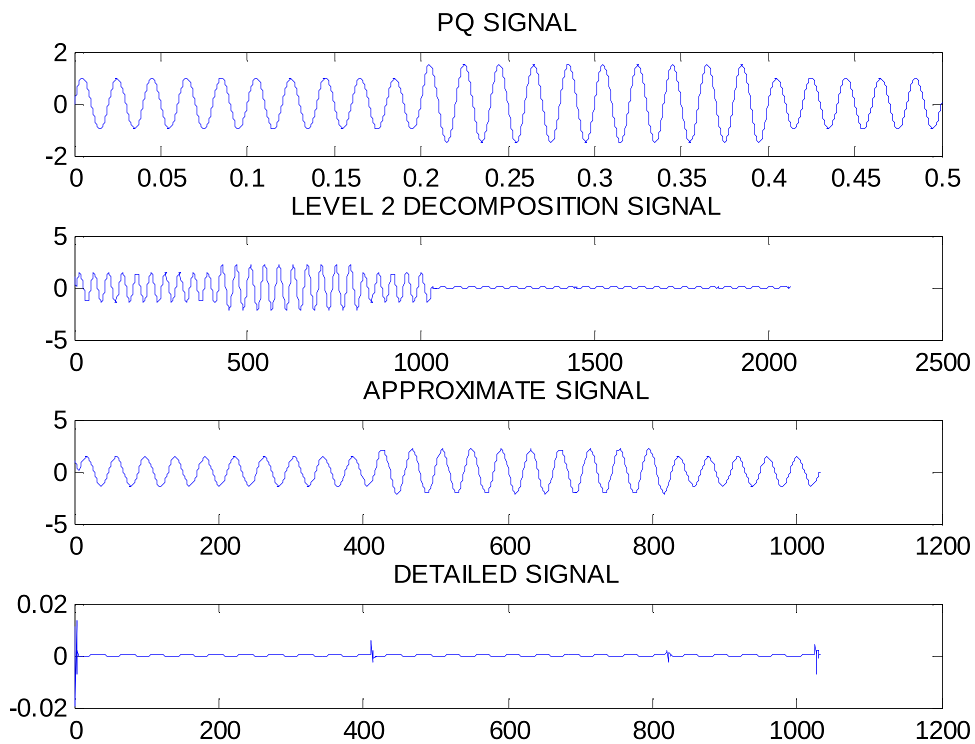

FIGURE10.VOLTAGE SWELL WITH 2ND LEVEL OF DECOMPOSITION

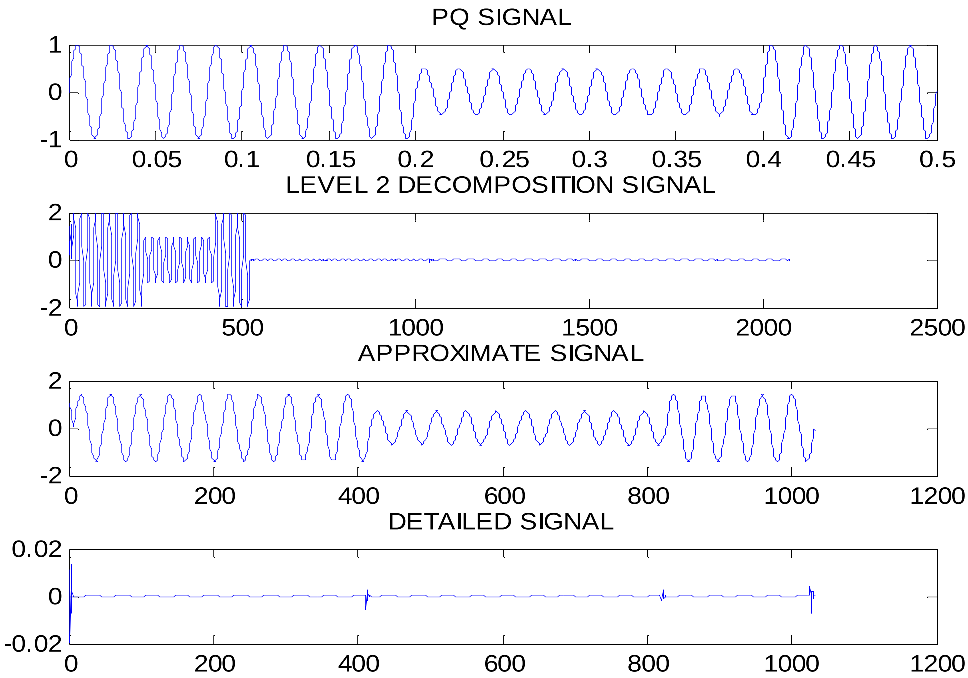

FIGURE11 .VOLTAGEINTERRUPTION WITH 2ND LEVEL OF DECOMPOSITION

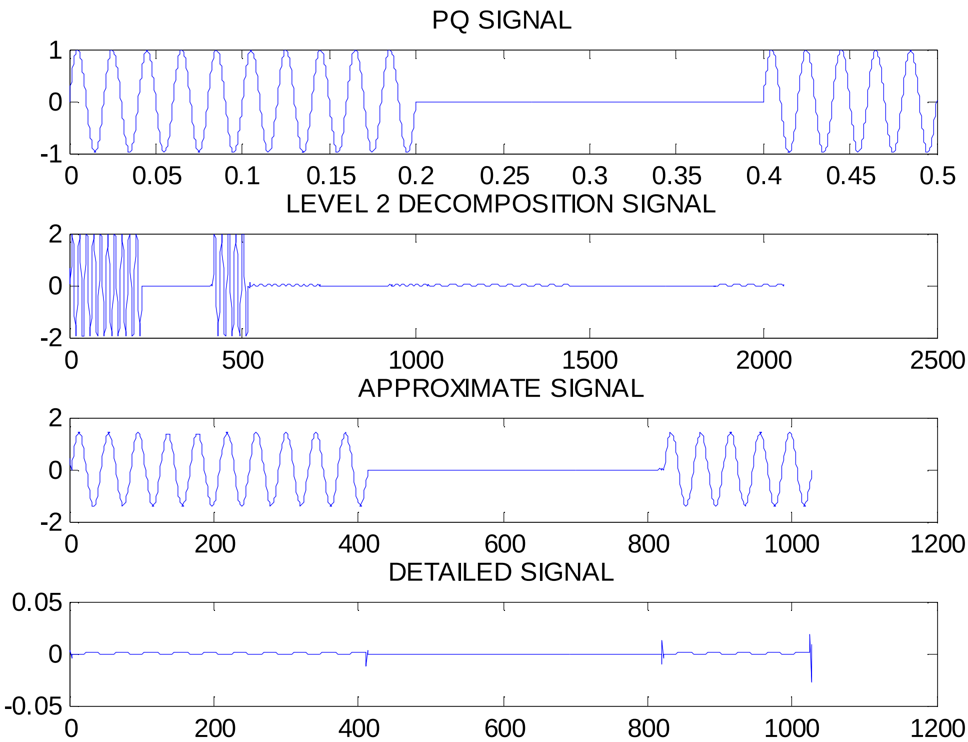

FIGURE12.VOLTAGE INTERRUPTION WITH 2ND LEVEL OF DECOMPOSITION

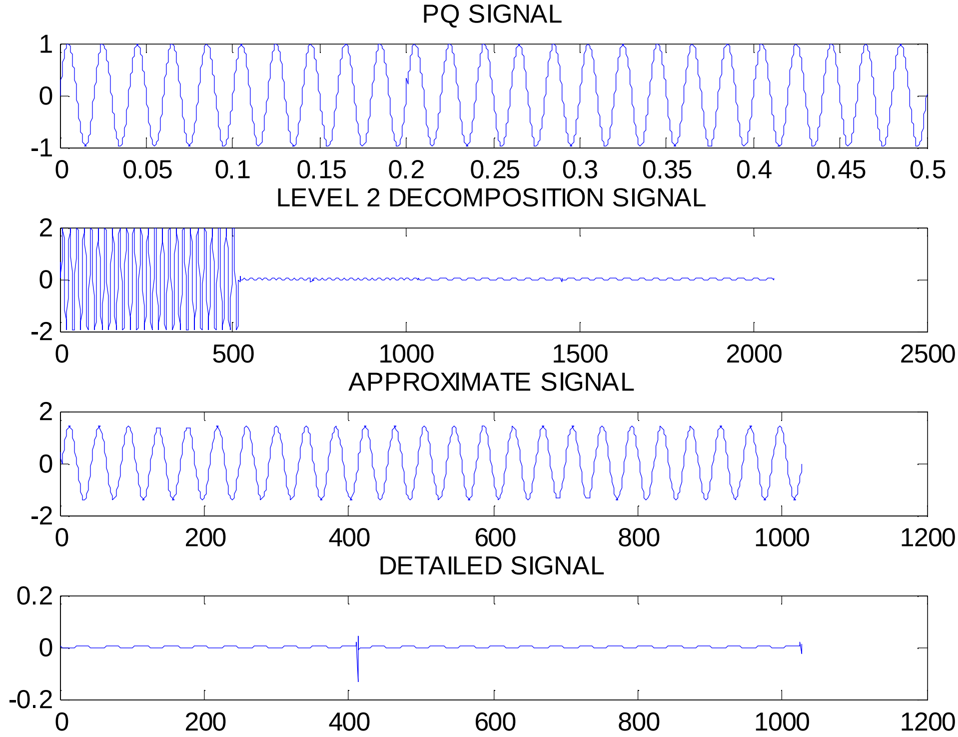

FIGURE13. VOLTAGE TRANSIENT WITH 2ND LEVEL OF DECOMPOSITION

Similarly we can obtain the third level of decomposition.The third decomposition level of only the sag with third and fourth order armonics signal is as shown.

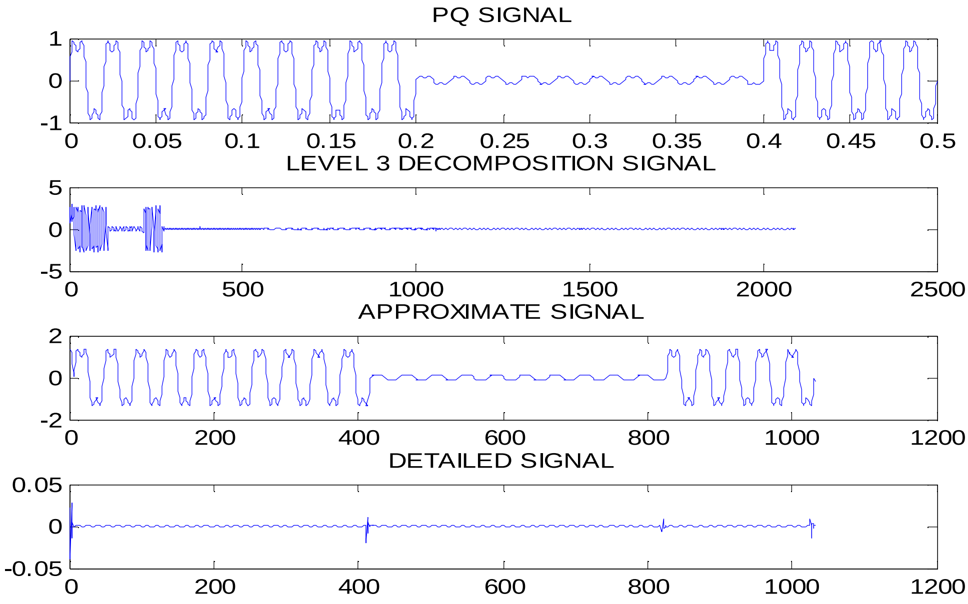

FIGURE14. VOLTAGE SAG ALONG WITH THIRD ORDER WITH 2ND LEVEL OF DECOMPOSITION

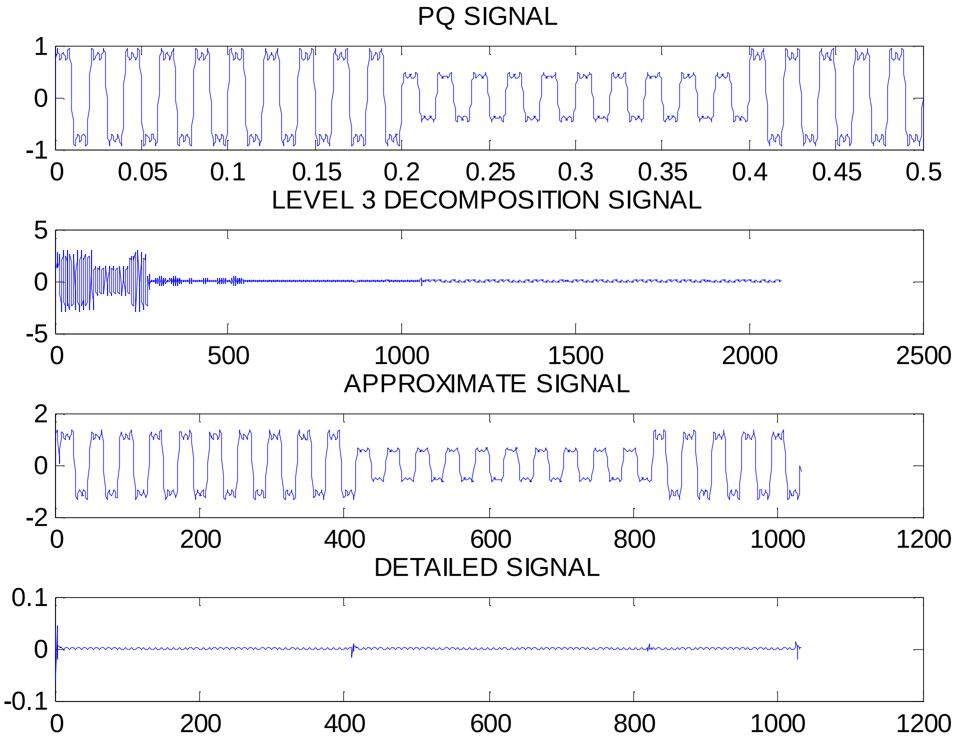

FIGURE15. VOLTAGE SAG ALONG WITH THIRD AND FIFTH ORDER WITH 2ND LEVEL OF DECOMPOSITION

Chapter III De-noising of PQ events

The main problem in the detection part of the PQ disturbances is noise. Most of the signals classification is greatly degraded in distinguishing the power quality distuerbances and noise. Hence before the classification of the signal, the signal must be de-noised. One of the application of the wavelet analysis is the de-noising by certain methods.

3.1 Steps involved in de-noising the signal

In general to DWT it involves the above two steps discussed in chapter II and one more thresh-holding. The three steps which are involved in de-noising are as follows:

1. **Decomposition:** As usual we have to select the mother wavelet as "db4" or Daub4 as they are compact. It is for high frequency and fast transients which means sharp changes. The level of decomposition is also selected which is 5 in this case.
2. **Detail coefficient thresh-holding**: For the detail coefficients a soft threholding method in MATLAB is chosen.
3. **Reconstruction:** Similar to the wavelet analysis, the reconstruction of the signal is the same to the reconstruction algorithm of Discrete Wavelet Transform (DWT)

3.2 Thresh-holding rule

Here all the signals are added with a Gaussian noise to add them as noise, the noisy signal is then decomposed into db4 or Daub4 by level 5 decoposition scheme. The noise signal is then decomposed by DWT to the same level to generate wavelet coefficients which are approximate and detail coefficients. Let S(n) be the noise signals with the PQ signal F(n).

$$\boldsymbol{S(n) = F(n) + \in . \, e(n)} \quad \textbf{(3.1)}$$

Where n=0,1,2..k-1 and e(n) corresponds to noise signal.

In MATLAB the common denoising they are:-

1. **"rigrsure"**
2. **"heursure"**
3. **"sqtwolog"**
4. **"minimax"**

'rigrsure' : It uses the soft threshold estimator. It is a a threshold selection rule based on the Stein's Unbiased Estimate of Risk (quadratic loss function).

'sqtwolog' It uses a fixed form threshold yielding 'minimax' performance multiplied by a small factor proportional to *log*(*length*(s)).

‘heursure' is a mixture of the two previous options. As a result, if the signal-to-noise ratio is very small, the SURE estimate is very noisy. So if such a situation is detected, the fixed form threshold is used.

'minimaxi' uses a fixed threshold chosen to yield minimax performance for mean square error against an ideal procedure.

3.3 Results of de-noising

As white Gauss noise is added to the signal and then the signal is de-noised using the thresh-holding schemes as discussed earlier. Now the different types of signals are denised using the above methods and the results are as shown in the figures:-

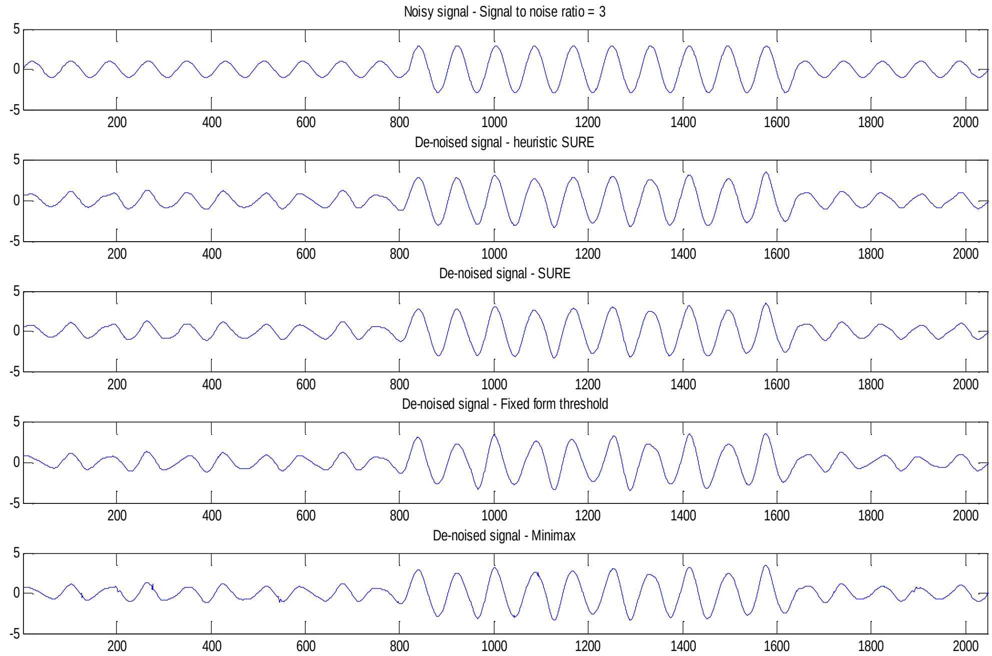

FIGURE16. DE-NOISED VOLTAGE SWELL SIGNAL

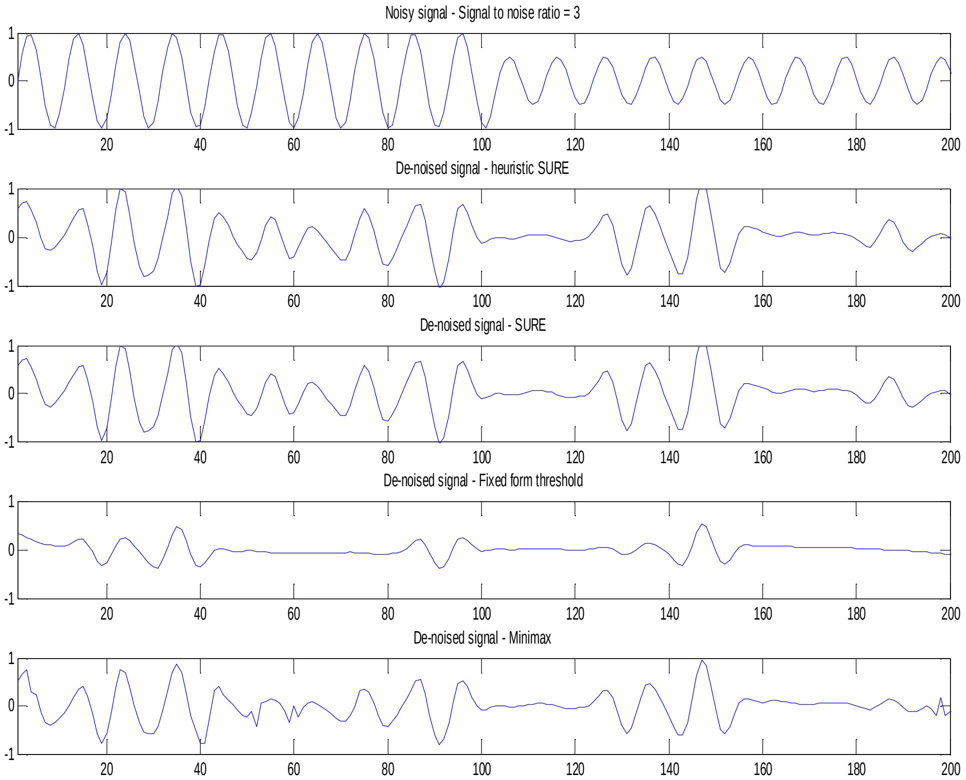

FIGURE17.DE-NOISED VOLTAGE SWELL SIGNAL

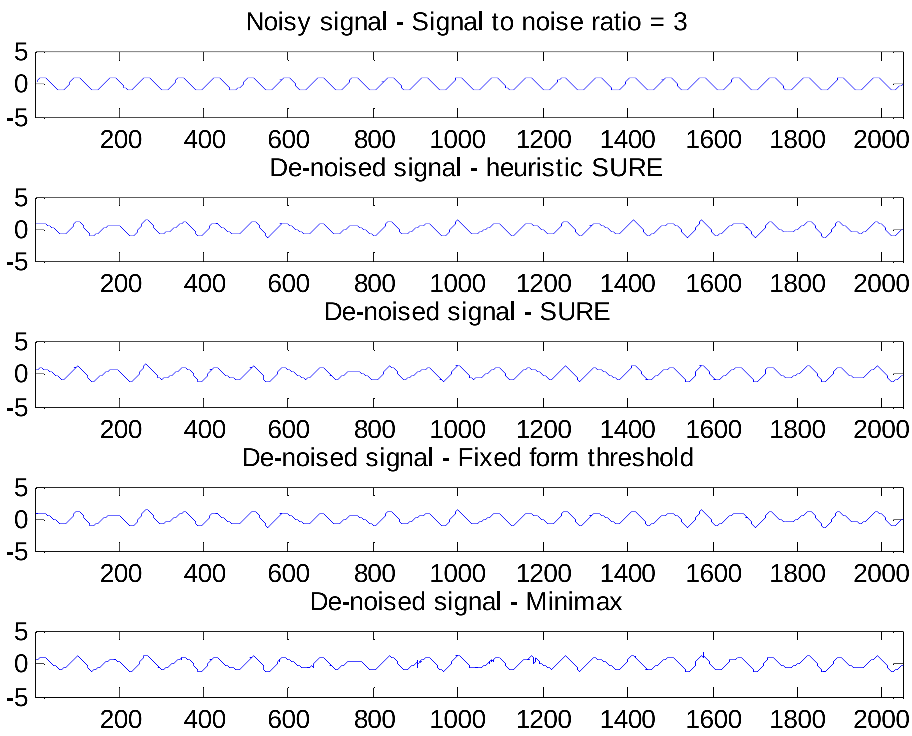

FIGURE18 DE-NOISED VOLTAGE TRANSIENT SIGNAL

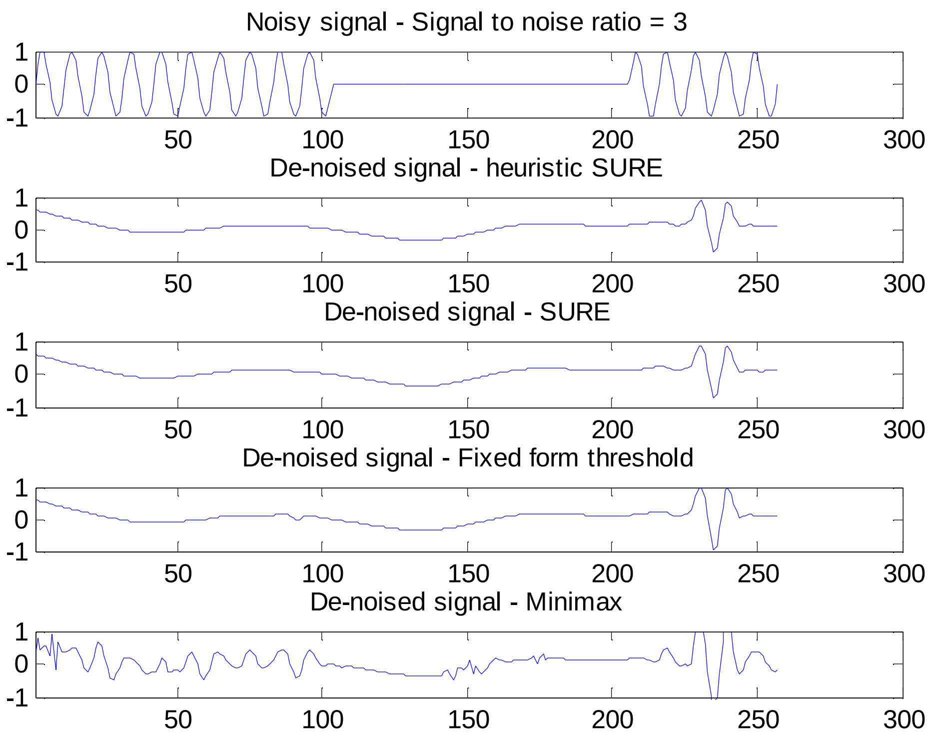

FIGURE19 DE-NOISED VOLTAGE INTERRUPTION SIGNALSIGNAL

Similarly for the transients and for the harmonic content level the de-noised signals are plotted

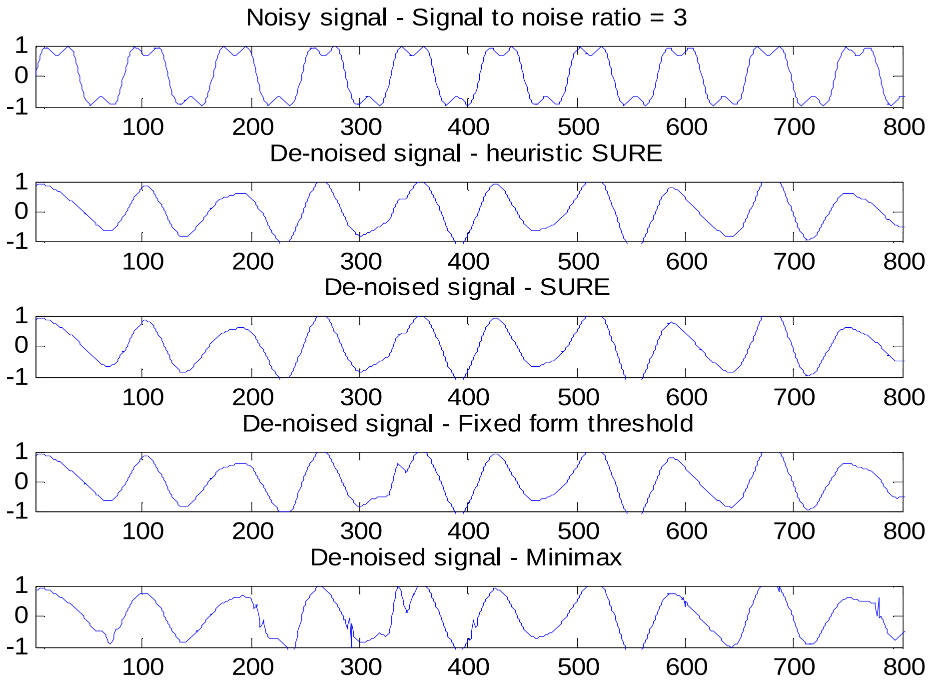

FIGURE20 DE-NOISED VOLTAGE SAG WITH THIRD HARMONIC SIGNAL

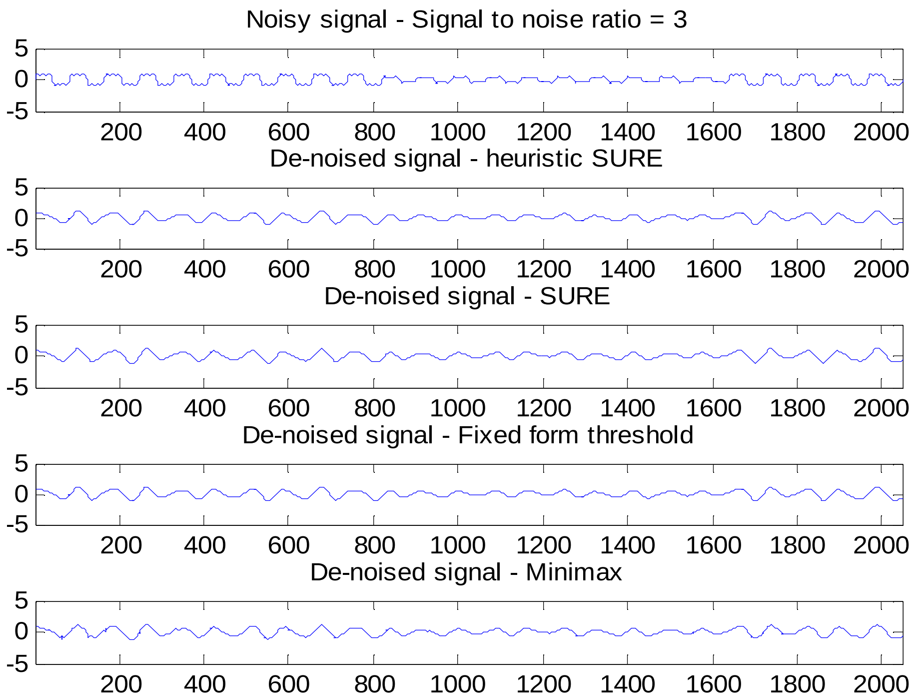

FIGURE21.DE-NOISED VOLTAGE SAG WITH THIRD AND FIFTH HARMONIC SIGNAL

CONCLUSION

Hence, after getting the result from this chapter it is quite evident that the DWT transformation helps a lot in de-noising of the signal. The thresh-holding technique is qutite efficient in de-niosing the signls from noise and most of them are cleared. After this the signals are sent for feature extraction using the basic perfomance indices like THD and Energy of the signal. The presence of the noise will have greatly affected in the classification of all the signals in PQ detection and classification.

Chapter IV Feature Extraction

4.1 Introduction

For the design of the monitoring scheme for the detection of the PQ disturbance signals the prime necessity is the extraction of the above de-noised signal. The feature extraction is quite important in designing the monitoring system. For that we have to have a database based on certain performance indices which will be in help to distinguish the PQ signals with less ambiguity and redundancy. The basic performance indices of the system are THD and Energy of the signal which will classify these signals into different PQ events.

4.2 Feature Extraction Vector

As discussed earlier the two parameters which help in classifying the above signals are THD and Energy of the signal. Another benefit in using the DWT transform theory is that we can easily get these two parameters using the coefficients of DWT.

THD (Total Harmonic Distortion)

In each frequency ranges, the distortion harmonics which are included can be detected by using the approximation and detail coefficient which are in turn obtained by Discrete Wavelet Transform (DWT).

In terms of RMS values

$$\boldsymbol{RMS = \sqrt{\frac{1}{N_j}\sum_n (CD(n)_j{}^2)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{4.1}$$

Where N(j) is the number of detail coefficient at scale j.

Hence, by these coefficients THD can be calculated as follows

$$\boldsymbol{THD = \frac{\sqrt{\frac{1}{N_j}\sum_n CD_j(n)^2}}{\sqrt{\frac{1}{N_i}\sum_n CA_j(n)^2}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{4.2}$$

Energy of the signal

Similarly, Energy of the signal is calculated as follows:

$$\boldsymbol{E = \int f(t)^2\, dt = \sum_k C(k)_j{}^2 + \sum_{j=1} 1 \sum_k D(k)_{jk}{}^2} \ldots\ldots\ldots\ldots\mathbf{4.3}$$

Where C(k)j and D(k)j are the approximate and detail coefficients respectively in the wavelet decomposition procedure.

4.3 PQ Database

As we have generated the various signals in MATLAB and then by Discrete Wavelet Transform decomposed into coefficients which are in turn used as for calculating the parameters of THD and Energy spectrum of the signal. Now for further we have de-noised the signal using the de-noising of the MATLAB and DWT functions which are fed input to the extraction of signal parameters namely THD and energy. So we have to make a database such that we can classify them in their PQ events without any ambiguity.

At first the signal with less parameter variations are tabulated as below:

TABLE3. TRANSIENT AND INTERRUPTION THD AND ENERGY

Type of PQ disturbance	THD magnitude	Energy in(volt^2 - second)
Transient	**0.6342**	$\mathbf{1.0214*10^3}$
Interruption	**0.6244**	$\mathbf{0.6140*10^3}$

VOLTAGE SAG

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V = (1-A*(u(t-t1)-u(t-t2))).*sin(2*pi*50*t);………………..………...4.4

Finally after de-noising and decomposition the following table is obtained as follows:

TABLE4. VOLTAGE SAG THD AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
10	0.525	$0.946*10^3$
20	.05205	$0.876*10^3$
30	0.5195	$0.815*10^3$
40	0.5200	$0.761*10^3$
50	0.5205	$0.716*10^3$
60	0.5211	$0.679*10^3$
70	0.5217	$0.651*10^3$
80	0.5225	$0.630*10^3$
90	0.5234	$0.618*10^3$

Hence, the threshold levels for the THD and for the energy signals are:

1. THD :0.5195 to 0.5250
2. ENERGY:(0.618 to0.946)*10^3

VOLTAGE SAG WITH THIRD HARMONIC

TABLE5. VOLTAGE SAG WITH THIRD HARMONICS THD AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
10	0.5362	$0.131*10^3$
20	0.5360	$0.121*10^3$
30	0.5359	$0.113*10^3$
40	0.5358	$0.105*10^3$
50	0.5357	$0.099*10^3$
60	0.5356	$0.094*10^3$
70	0.5355	$0.0903*10^3$
80	0.5354	$0.087*10^3$
90	0.5352	$0.085*10^3$

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V=(1-A*(u(t-t1)-u(t-t2))).*(sin(2*pi*50*t)+(0.333*(sin(2*pi*50*3*t)))........................(4.5)

Hence, the threshold levels for the THD and for the energy signals are:

1. THD :0.5352 to 0.5362
2. ENERGY: (0.085 to 0.131)*10^3

VOLTAGE SAG WITH THIRDAND FIFTH HARMONIC

TABLE6. VOLTAGE SAGWITH THIRD AND FIFTH HARMONICS THD AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
10	0.54541	$1.089*10^3$
20	0.54564	$1.0886*10^3$
30	0.54584	$0.938*10^3$
40	0.54562	$0.876*10^3$
50	0.54565	$0.824*10^3$
60	0.54578	$0.782*10^3$
70	0.54572	$0.749*10^3$
80	0.54575	$0.725*10^3$
90	0.54598	$0.711*10^3$

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V =(1-A*(u(t-t1)-u(t-t2))).*(sin(2*pi*50*t)+

(0.333*(sin(2*pi*50*3*t)))+(0.2*(sin(2*pi*50*5*t))))……………………..4.6

Hence, the threshold levels for the THD and for the energy signals are:

1. THD : 0.54551 to 0.54598
2. ENERGY: $(0.711 \text{ to } 1.0089) * 10^3$

VOLTAGE SWELL

TABLE7. VOLTAGE SWELL THD AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
110	0.53323	$1.0889*10^3$
120	0.53414	$1.0850*10^3$
130	0.53512	$1.0654*10^3$
140	0.53617	$1.0589*10^3$
150	0.53721	$1.0515*10^3$
160	0.53769	$1.0423*10^3$
170	0.53775	$1.0398*10^3$
180	0.53819	$1.0129*10^3$
190	0.53897	$1.0091*10^3$

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V=(1+A*(u(t-t1)-u(t-t2))).*sin(2*pi*50*t);…….4.7

Hence, the threshold levels for the THD and for the energy signals are:

1. THD :0.53323 to 0.53897
2. ENERGY: $(1.0191 \text{ to } 1.081) * 10^3$

VOLTAGE SWELL WITH THIRD HARMONICS

TABLE8. VOLTAGE SWELL THD WITH THIRD HARMONICS AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
110	0.5548	$1.23120*10^3$
120	0.5549	$1.33780*10^3$
130	0.55434	$1.45150*10^3$
140	0.55384	$1.57440*10^3$
150	0.55338	$1.70630*10^3$
160	0.55294	$1.84740*10^3$
170	0.55252	$1.99750*10^3$
180	0.55214	$2.15680*10^3$
190	0.55178	$2.32520*10^3$

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V=(1-A*(u(t-t1)-u(t-t2))).

***(sin(2*pi*50*t)+(0.333*(sin(2*pi*50*3*t))));………….........4.8**

Hence, the threshold levels for the THD and for the energy signals are as per the database are

1. THD : 0.55178 to 0.5548
2. ENERGY: (1.22 to 2.01) $* 10^3$

VOLTAGE SWELL WITH THIRD AND FIFTH HARMONICS

TABLE9. VOLTAGE SWELL THD WITH THIRD AND FIFTH HARMONICS AND ENERGY

MAGNITUDE OF DISTURBANCE(%)	THD	ENERGY(volt^2 –sec)
110	0.54501	$1.2775*10^3$
120	0.54483	$1.3850*10^3$
130	0.54467	$1.5030*10^3$
140	0.54451	$1.6311*10^3$
150	0.54437	$1.7680*10^3$
160	0.54423	$1.9139*10^3$
170	0.54410	$2.0690*10^3$
180	0.54394	$2.2345*10^3$
190	0.54387	$2.4084*10^3$

The voltage sag signal is maintained with disturbance time of (0.2-0.4) seconds. After that the disturbance level is varied from 0.1 to 0.9

V =(1+A*(u(t-t1)-u(t-t2))).

***(sin(2*pi*50*t)+(0.333*(sin(2*pi*50*3*t)))+(0.2*(sin(2*pi*50*5*t))))………………..4.9**

Hence, the threshold levels for the THD and for the energy signals are:

1. THD : 0.54387 to 0.54501
2. ENERGY: $(1.2 \text{ to } 2.4) * 10^3$

Chapter V Classification and Conclusion

The flow chart for the given classification scheme is given below:

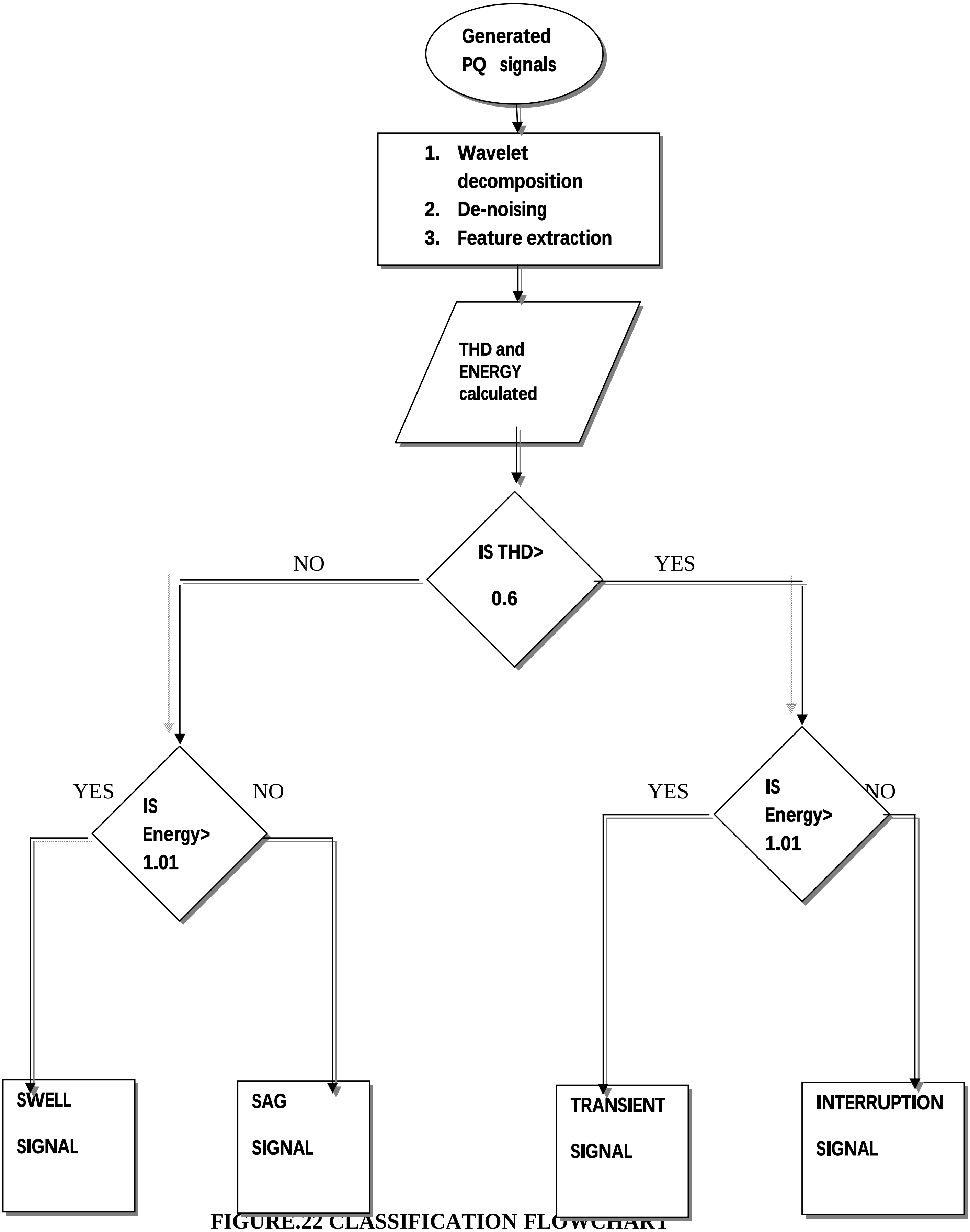

FIGURE.22 CLASSIFICATION FLOWCHART

Conclusion

In this part of the work different PQ disturbances with different fault magnitude are generated and the feature vector containing Energy and THD are extracted based on the equation (4.2) and equations as discussed in section 4.2 and a database is prepared. It is observed that the value of THD and Energy is increased considerably if the PQ disturbance contains harmonics. By looking in the database of the PQ disturbance signals, it is quite convenient that different PQ signals are associated with different sets of THD and Energy for example the voltage interruption signal has the lowest energy whereas the Swell signal has the highest energy. For taking the corrective measures in the power system, there is a need of correctly detecting and estimating the PQ disturbances in a processed manner .For the study here we have taken nearly six types of signals including harmonics and noise along with sag and swell signals. The first step includes finding the coefficients of decomposition by DWT and reconstruction algorithm. The WT is an approach in frequency domain where the signals are analysed at different frequency resolution levels. The only problem in the detection is that the noise level, if present in the signal then signal classification is much more difficult. Therefore, we have to de-noise the signals again by using DWT different methods of functions. After de-noising of the signals we have to extract the feature vectors like THD and energy of each signals and then classifying them into their different PQ events by selecting some threshold values. Finally a flow cart have been prepared to show different classifications in Figure.22

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